THE EFFECTS OF SELECTIVE BAND REJECTION FILTERING ON SPEECH INTELLIGIBILITY OF INDIVIDUALS WITH SENSORI-NEURAL DYSACUSIS

By
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The purpose of this investigation was to determine whether individuals with high frequency sensori-neural hearing losses could achieve improved speech intelligibility through selective band rejection filtering.

Monaural intelligibility scores for PAL-8 Sentence Sets were obtained from ten subjects representing two sensori-neural hearing loss contour types: relatively flat losses and ski slope losses. Intelligibility scores were obtained from the five subjects within each hearing loss contour type under four filtering conditions:

Condition HF -- High frequency emphasis
Condition BR -- Band rejection
Condition LP -- Low pass
Condition SA -- Subject adjusted

Filter Condition HF provided 4 to 6 dB per octave high frequency emphasis from 300 to 4000 Hz with sharp cutoffs above and below. Filter Conditions BR, LP and SA were obtained by re-filtering the Condition HF high frequency emphasis response. Filter Condition LP provided low pass filtering with an upper cutoff frequency of 1600 Hz. Filter settings for Conditions HF and LP were the same for all subjects.

Settings for Condition BR were determined for each subject by having him listen to a passage of continuous discourse, previously subjected to high frequency emphasis filtering, as the experimenter rejected 1/3 octave bands at center frequencies from 1600 to 4000 Hz. Band rejections leading to increased judged intelligibility by the subject were noted and used in the Filter Condition BR test presentation.

Condition SA settings were obtained for each subject by having him listen to the passage of continuous discourse while he manipulated the filter attenuators, within the frequency range of 400 to 4000 Hz, until he judged the speech most intelligible. Filter settings at maximum judged intelligibility were used for Filter Condition SA presentations.

The effect of each filter condition on speech intelligibility was determined in quiet and in the presence of a competing speech masking stimulus at 0 dB signal/noise ratio. Filtered speech test materials were presented at 6 dB above the most comfortable loudness level established for that filter condition.

Intelligibility scores were subjected to a nested factorial analysis of variance which indicated a significant difference (.01 level) in the effects of filter conditions on speech intelligibility. Application of Duncan's New Multiple Range Test revealed Filter Condition LP speech intelligibility to be significantly poorer than for Conditions HF, BR or SA; while no significant differences were found to exist among Filter Conditions HF, BR and SA. A significant difference (.01 level) in speech intelligibility measured under the quiet and masked conditions was also noted, with masking causing a substantial reduction of speech intelligibility. Significant individual differences (.01 level) in speech intelligibility were found to exist among subjects within the two hearing loss contour types. However, the difference in average speech intelligibility of the two hearing loss contour type groups did not reach significance at the .05 level.

Two interaction effects were found to be significant at the .05 level: the presentation-by-subject interaction and the filter-by-presentation-by-subject interaction. The remaining filter-by-presentation, filter-by-hearing loss type, presentation-by-hearing loss type, filter-by-subject, and filter-by-presentation-by-subject interactions were not significant at the .05 level.

The results do not support the experimental hypothesis of improved speech intelligibility for persons with sensori-neural hearing losses through selective band rejection filtering. The findings do demonstrate the important contribution of frequencies above 1600 Hz to speech intelligibility by individuals with sensori-neural hearing losses. The results also illustrate the difficulty experienced by hearing-impaired individuals in making subjective evaluations of speech amplification systems, and the detrimental effect of competing speech masking on speech intelligibility.

CHAPTER I

Introduction

The Problem

Through the use of modern electro-acoustic hearing aids, many hearing-impaired individuals are able to overcome their hearing handicaps and maintain effective auditory communication. Unfortunately, not all hearing-impaired individuals are able to achieve satisfactory auditory functioning through hearing aid amplification. Frequently the individual with substantial cochlear pathology experiences aided speech discrimination so poor as to rule out the use of a hearing aid. The belief is widely held that this reduction of speech discrimination ability may be due in part to distortion generated in the pathological cochlea, the amount of distortion produced being proportional to both the degree of cochlear lesion and speech intensity.

Statement of Purpose

The purpose of this investigation was to determine whether or not individuals with high frequency sensori-neural hearing losses could achieve improved speech intelligibility through selective band rejection filtering of frequency regions of the speech signal which possibly contribute more to cochlear distortion than to intelligibility.*

Related Studies

The ear with cochlear lesion often manifests not only a loss of auditory sensitivity but also a reduction of speech discrimination ability. This reduction in speech discrimination frequently makes the use of amplification less effective than in cases of conductive loss. In speaking of cochlear lesions, McConnell (1960) states:

> Although hearing aid amplification may provide improvement of sensitivity for speech, it frequently does not improve the finer auditory discrimination on which the understanding of speech is dependent. So even though an aid may be able to amplify those frequencies responsible for discrimination, the cochlea is unable to transform them properly into nerve impulses and speech intelligibility is lost.

Recent determination of the articulation functions for ears with cochlear lesions by Tillman and Carhart (1965) has confirmed the clinical finding that these ears often fail to reach high levels of discrimination ability even though the speech signal is made adequately loud through amplification.

Considerable research evidence points to the pathological cochlea as a prime contributor of distortion leading to reduced speech discrimination. This distortion is commonly manifested by loudness recruitment, restricted dynamic range, or the production of aural harmonics. In considering the use of hearing aid amplification in ears with cochlear lesions, Yantis (1956) states:

---

*Throughout the remainder of the paper the term "sensorineural" will refer to losses due to cochlear lesions.

> It is often recognized that those patients having the greatest difficulty in the effective use of hearing aids are those who have a perceptive type loss. It is reasonable to account for this, at least in patients with inner ear involvement, because of the characteristically restricted dynamic range of response to sound in these individuals. Aural distortion is introduced at a much lower level above threshold than in those with a conductive loss or in those, it is presumed, with an involvement of the auditory nerve alone.

The presence of loudness recruitment is now thought to be diagnostically indicative of cochlear lesion and is believed to be a major contributing factor to the decreased intelligibility of amplified speech for persons with sensori-neural losses (Jerger, 1962; Hallpike, 1967; Graham, 1967). Feldman (1964) summarizes the clinical findings concerning loudness recruitment and speech discrimination as follows:

> Loudness recruitment is felt to be one factor resulting in the poor speech discrimination frequently associated with sensori-neural losses. Knowledge as to the presence and amount of recruitment has bearing upon the patient's prognosis with amplification. In extreme cases, tolerance and discrimination problems may rule out the use of amplification.

Lawrence and Yantis (1956) suggest the threshold of aural overload as an indicator of nonlinear cochlear distortion. Ears with cochlear pathology were found to have greatly reduced dynamic ranges. It was concluded that:

> If the inner ear becomes involved the threshold of overload is lowered and the range from threshold to overload becomes markedly restricted. There also, obviously, is a relationship to the recruitment phenomenon, since in every case where recruitment occurs there is a lowering of this overload threshold. With a linear range of only 18 to 24 dB in these two frequencies (1000 and 2000 Hz) the ear obviously will not render a very recognizable pattern when fed by a hearing aid or even a loud voice that has a range greater than this (Lawrence and Yantis, 1956).

Yantis, Millin and Shapiro (1966) carried out two experiments to determine the role of speech intensity level on discrimination ability in ears with sensori-neural losses. Experiment I established that for the great majority of ears with cochlear lesions, the intensity above SRT at which speech stimuli of relatively good fidelity could best be discriminated was no more than 10 dB above the level at which aural harmonics occurred. This finding was even more definite when speech material of poorer fidelity was employed. These results tend to support the hypothesis that optimum discrimination for speech in ears with cochlear lesion is obtained at an intensity level which is within or only slightly above the linear range of the ear. In Experiment II it was found that individuals with cochlear lesions who were experienced users of hearing aids consistently adjusted the gain of their instruments to provide a stimulus intensity at which speech discrimination was maximal and which was within the linear range of their hearing. Considerably reduced discrimination scores were frequently found at gain levels only slightly higher than that at which maximum discrimination was obtained. It was speculated that "this reduction in discrimination ability might be explained by the production of aural harmonics as the ear is driven into nonlinearity, as well as by distortion by-products in the hearing aid itself " (Yantis, Millin and Shapiro, 1966).

According to Thompson and Lassman (1969), it is not clear what type of amplification to provide for patients with high frequency sensori-neural losses. Early attempts at selective amplification or threshold curve fitting met with little success (Watson and Knudsen, 1940). Selective amplification was based on the assumption that by amplifying those frequencies most severely impaired, a balance of sensitivity could be re-established, leading to normal speech perception. It now appears that selective amplification was based on assumptions failing to take into account the complex nature of the resultant cochlear lesion hearing impairment, and neglecting the effects of cochlear distortion on the acoustic signal and subsequent speech perception. Thompson and Lassman (1969) report objections to the use of selective amplification in that:

> It is based on an oversimplified view of the auditory system which does not take into account abnormal auditory behavior often associated with sensori-neural hearing loss. For example, recruitment often produces a flattening of equal-loudness contours at suprathreshold levels. If recruitment is present, the intensity-frequency relationship at suprathreshold levels may not bear any resemblance to the threshold curve. Therefore, selective amplification on the basis of the threshold curve is not likely to be the best method for restoring frequency-intensity balance to the auditory system.

The most widely accepted standard of hearing aid response characteristics is that established by Davis, Hudgins, Marquis, Nichols, Peterson, Ross and Stevens (1946). According to these authors, "Experimental evidence seems to show that the principle of 'selective amplification' to compensate for impairment of hearing is fallacious." Based on controlled investigations, with both normal and pathological ears, Davis (1947) reached the following conclusions regarding optimal hearing aid response characteristics:

> The electro-acoustic properties best suited to one type of hearing loss are those best suited to all or nearly all. Regardless of the nature of their particular defect, most patients hear best with an instrument which amplifies all frequencies uniformly or with moderate emphasis of the higher frequencies.
>
> The ideal electro-acoustic specifications or design objectives for hearing aids should be as follows: The frequency response and range should be uniform without resonant peaks or valleys from 300 to 4000 cps. Sharp cutoffs below and above this range are desirable. The one best frequency characteristic is moderate high-tone emphasis of from 4 to 6 dB per octave over this range.

Littler (1965) reported the results of the British Medical Research Council investigation of 1947 into the design and development of electro-acoustic hearing aids to be in close agreement with the Harvard study of Davis, et al. (1946), except for cases with severe high frequency sensori-neural losses. According to Littler the British Medical Research Council concluded that:

> For patients who have a hearing loss increasing above 1000 c/s, it is apparently better to reduce the gain in these high frequency regions somewhat, a conclusion in conflict with a fairly widespread view

> at that time, namely that the frequency response of an aid should be adjusted to compensate for the frequency variation of the hearing loss curve.
>
> In the case of severe high frequency perceptive loss, there is physiological evidence against matching the response of a hearing aid to that of the audiogram. When the cochlea has become severely deafened in the high frequency regions it is probable that it is not capable of the same degree of analysis in these regions, and therefore more logical to devote sound energy to those regions of the cochlea which are more nearly normal.... Further, if a hearing aid is used with added high frequency gain the patient objects to the character of the response, as well as scoring a lower articulation.

Thompson and Lassman (1969) conducted an experiment to assess the differential effects of selective high frequency emphasis (15 dB per octave rejection rate below 1000 Hz) vs. flat amplification on the speech discrimination of subjects with high frequency sensorineural losses. Losses were classified into low or high distortion types based on Bekesy, SISI, tone decay and suprathreshold loudness tracking test results.

> It was hypothesized that subjects with least distortion discriminate speech better through a selective high-pass filtered system and that subjects with most distortion discriminate speech better through a flat system. Results for SSC material suggest that amplification type is related to amount of auditory distortion, but only to the extent encompassed in the first part of the hypothesis, referring to the selective amplification-low distortion relationship. Amplification type did not seem to make any difference for the high distortion group. Distortion in the auditory system may serve to modify the extent to which filtered amplification is superior to flat amplification for patients with high frequency hearing loss (Thompson and Lassman, 1969).

The importance of a flat frequency response without peaks or valleys, suggested by Davis, has been questioned by Jerger (1968). Results of a study using both normal and pathological ears indicated that regularity in the frequency response of a hearing aid is an important factor contributing to intelligibility of speech for normal-hearing listeners. However, decreased frequency response irregularity tended to be of little value in improving the intelligibility of aided speech for persons with moderate to steeply sloping sensori-neural losses. Jerger concluded:

> There are physical indices of hearing aid performance that relate strongly to behavioral results, namely response irregularity and effective bandwidth, but that the relationships are most important for normal listeners and least important for hearing-impaired patients with steeply sloping losses (Jerger, 1968).

Huizing and Reyntjes (1952) found ears with high frequency sensori-neural losses, accompanied by recruitment, to yield maximum speech discrimination at low sensation levels and to decrease rapidly in discrimination ability with further increases in speech intensity level. They believed that the loss of discrimination ability with increasing speech level could be accounted for by the growth of physiologic noise or distortion. Huizing and Reyntjes suggested, in direct contrast to selective amplification or the approach of Davis, that in cochlear lesions involving recruitment or other cochlear distortions intelligibility might be improved by partial suppression of frequency bands contributing maximally to distortion. Huizing and Reyntjes recommend that through band clipping or partial suppression the aided frequency response be shaped "so that the center of intelligibility is moved to a part of the frequency scale, in which the subjective distortion is as low as possible, while the contributing bandwidth still remains large enough to obtain better conditions." The present investigation is concerned with this suggested selective filtering approach to speech amplification.

Abundant experimental evidence exists demonstrating the redundant character of the speech signal (French and Steinberg, 1947; Palva, 1965; Pollack, 1948; Egan and Weiner, 1946). Kryter (1960) found that considerable band rejection filtering could be performed while still maintaining good speech intelligibility. Sentence materials and PB words were presented at a constant level of approximately 75 dB SPL while various 500 Hz passband combinations were presented. Using a single 500 Hz passband, the frequency range from 1600 to 1700 Hz was found to contribute most to intelligibility. Intelligibility was found maximum for two 500 Hz passbands with center frequencies at 500 Hz, and 1500 or 2500 Hz. With three 500 Hz passbands, center frequencies of 500, 1500 and 2500 Hz were found most intelligible, yielding approximately 95% intelligibility, the lower band contributing most and the higher band least to intelligibility. These three center frequencies roughly approximate the first three vowel formant regions. It was concluded that the best contiguous passband system requires twice the effective bandwidth as the best three-passband system to achieve equal speech intelligibility. This finding was explained in terms of a more adequate sampling of the speech signal, better resistance to noise interference and decreased close frequency masking.

Experimental Design and Test Hypotheses

In order to evaluate the possible benefits of band rejection filtering on speech intelligibility the present study was designed to measure the effects of four filtering conditions

1. HF -- High frequency emphasis
2. BR -- Band rejection
3. LP -- Low pass
4. SA -- Subject-adjusted filtering

on the intelligibility of amplified speech by subjects having high frequency sensori-neural hearing losses. Subjects were chosen to represent two general hearing loss contour types based on pure tone threshold test results: Type 1 -- relatively flat losses, and Type 2 -- ski slope losses. The effect of each filtering condition on speech intelligibility was determined under two presentation conditions, in quiet and in the presence of a competing speech masking stimulus.

Speech intelligibility scores obtained under the experimental conditions were subjected to a nested factorial analysis of variance design (Hicks, 1964), with hearing loss types nested within the population of sensori-neural losses. This design allowed testing of hypotheses concerned with the three main fixed effects (filter conditions, hearing loss types, and quiet vs. masked presentation conditions) as well as the testing of interaction effects.

Specific hypotheses investigated, stated in the null form, are as follows:

1. There are no significant differences in speech intelligibility of the two hearing loss type groups.

2. There are no significant differences in speech intelligibility of subjects within hearing loss type groups.

3. There are no significant differences in the effects of the four filter conditions on speech intelligibility.

4. There are no significant differences in speech intelligibility due to the two presentation conditions.

5. There are no significant interaction effects among filter and presentation conditions affecting speech intelligibility.

6. There are no significant interaction effects among filter conditions and hearing loss types affecting speech intelligibility.

7. There are no significant interaction effects among presentation conditions and hearing loss types affecting speech intelligibility.

8. There are no significant interaction effects among filter conditions, presentation conditions and hearing loss types affecting speech intelligibility.

9. There are no significant interaction effects among filter conditions and subjects affecting speech intelligibility.

10. There are no significant interaction effects among presentation conditions and subjects affecting speech intelligibility.

11. There are no significant interaction effects among filter conditions, presentation conditions and subjects affecting speech intelligibility.

An F test value at the .05 level of significance was required for rejection of null hypotheses.

CHAPTER II

Procedure

Subjects

The experimental group was composed of ten male subjects having moderate-to-severe high frequency sensori-neural hearing losses. The mean age of the experimental group was 55 years. Each subject received a pre-test evaluation which served four purposes in the study:

1. To obtain information concerning the site of lesion and degree of hearing loss;
2. To determine specific filter condition settings to be used with each subject;
3. To establish speech reception thresholds (SRT) and most comfortable loudness levels (MCL) for each of the filtered speech test conditions;
4. To provide practice in listening and responding to filtered speech materials.

Classification as to site of lesion and degree of hearing loss was based on:

1. Conventional pure tone air and bone conduction audiometry;
2. Conventional clinical Bekesy audiometry (Jerger, 1960);

3. Administration of the SISI test at 1000, 1500, 2000, 3000 and 4000 Hz (Jerger, Shedd and Harford, 1959);

4. Otologic examination by the Otorhinolaryngology staff of the Veterans Administration Hospital, Gainesville, Florida.

Subjects were classified into two hearing loss contour type groups, of five each, on the basis of pure tone threshold test results:

Hearing Loss Contour Type 1 --	Moderate losses for frequencies below 1000 Hz, with moderate-to-severe losses for frequencies above 1000 Hz (relatively flat loss).
Hearing Loss Contour Type 2 --	Hearing sensitivity within normal limits or showing mild losses for frequencies below 1000 Hz, with steep falling moderate-to-severe losses above 1000 Hz (ski slope loss).

Only one ear of each subject was used experimentally. Results of the pure tone pre-test evaluation for each subject are presented in Appendix A.

Equipment

Tape recordings of the speech test material were made on an Ampex 602-2 Tape Recorder using a Bruel and Kjaer Condenser Microphone, Type 4132, and associated Microphone Amplifier, Type 2603.

A Bruel and Kjaer Spectrum Shaper, Model 124, was used for filtering the test tapes. For use in this study, the shaper frequency response was limited to a series of eleven contiguous 1/3 octave filters, with lower and upper cutoff frequencies at 400 and

4000 Hz, as shown in Appendix B, Figure 1. Individual alide attenuators provided maximum notch attenuation for each filter of at least 25 dB with a maximum attenuation slope of 50 dB per octave or greater. Spectrum shaper center frequencies and notch attenuation bandwidths at maximum attenuation for single and double center frequency band rejections from 1600 to 4000 Hz are presented in Appendix B, Table B-1. Filtered speech test tapes were channeled through a Grason-Stadler Speech Audiometer, Model 162, into a single TDH-49 earphone for test presentation.

A pure tone calibration check was made of the complete speech presentation system functioning as a unit. Pure tone stimuli, at 1/3 octave frequencies from 400 to 4000 Hz, were recorded on the Ampex Tape Recorder and fed through the spectrum shaper and speech audiometer into the TDH earphone. Sound pressure level measurements revealed the frequency response of the system to be linear from 400 to 4000 Hz within ∓ 2 dB with the spectrum shaper attenuators set at zero.

Speech Intelligibility Test Material

Thompson and Lassman (1969) stressed the critical importance of the choice of speech material when attempting to differentiate among amplifying systems or measure speech intelligibility. Lehiste and Peterson (1959) caution, in regard to the use of isolated sounds or nonsense syllables:

> There is considerable question as to whether the use of isolated sounds or nonsense syllables is significant in communication measurement. First of all nonsense syllables have no meaning and thus no intelligibility; second, the composition of such syllables by definition does not follow the normally allowed sequences of the language, and thus the sounds uttered in nonsense syllables are not appropriate representatives of the phonemes of the language. Since there is considerable influence between adjoining speech sounds, the acoustical characteristics of the vowels and consonants are indeed different from those within normal linguistic sequences.

Although routinely employed clinically for speech discrimination measurement and hearing aid evaluations, the use of monosyllabic phonetically balanced (PB) word lists has also been questioned. Shore, Bilger and Hirsh (1960) concluded, in reference to the CID W-22 lists and recorded PB lists of Rush Hughes, that the reliability of these measures was " ...not good enough to warrant the investment of a large amount of clinical time with them in selecting hearing aids." This conclusion was reaffirmed by the finding of Jeffers (1960) that aids differing in frequency response could not be differentiated on the basis of PB test results and the finding of Zerlin (1962) that aids meaningfully rank-ordered by means of a preference judgement could not be differentiated by means of W-22 word lists.

The use of sentence materials for speech intelligibility testing has high face validity in terms of proximity to conversational speech patterning. Jerger, Malmquist and Speaks (1966) describe PAL Auditory Test-8 and offer it as a means of effectively differentiating among amplification systems having various acoustic characteristics. The PAL-8 Test, originally constructed by Karlin, Abram, Sanford and Curtis (1944), is a multiple-choice sentence intelligibility test. Table I shows two typical questions and the four alternative answers for each.

TABLE I

PAL-8 Sentence Set Samples

1. The cold weather ends in:
   a. furnaces
   b. freezing
   c. tickling
   d. Spring

2. When it gets very cold water becomes:
   a. North-pole
   b. winter
   c. ice
   d. mines

Sentences are constructed in such a way that the listener must hear most or all of the key words in order to arrive at the correct answer. This reduces the possibility of correct single-word identification responses and increases the difficulty of the listening task. Karlin, et al. (1944), report an odd-even reliability coefficient of .91 for the PAL-8 sentences after administration to 191 subjects.

Jerger, Speaks and Malmquist (1966), using normal and pathological ears, found the PAL-8 Test to be a sensitive behavioral measure of hearing aid response characteristics. In a later study, Jerger, Malmquist and Speaks (1966) compared aided intelligibility scores obtained using PAL-8 Sentence Sets, CID Auditory Test W-22 (Hirsh, 1952), CNC Word Lists (Lehiste and Peterson, 1959) and PAL PB Word Lists. The PAL-8 test was found to differentiate among aids having varying acoustic characteristics while the monosyllabic word lists did not.

Tape recordings of the PAL-8 sentences served as the speech stimuli for this investigation. Four sentence sets of 25 sentences each were recorded on an Ampex 602-2 Tape Recorder by a male speaker using the Bruel and Kjaer Condenser Microphone and associated microphone amplifier. Recordings were made at 7 1/2 IPS on Scotch Brand 201 Magnetic Tape. Approximately constant voice level was maintained during sentence recording through VU meter monitoring. The four test sentence sets, designated Sentence Sets W, X, Y and Z, are presented in Appendix C along with their associated multiple-choice answers.

Thompson and Lassman (1969) suggested that differences between amplifying systems are less likely to be apparent if the discrimination task is easy. In order to make the PAL-8 Sentence Set intelligibility task more difficult, sentence sets W and X were always presented with a competing speech masking stimulus. The masking stimulus consisted of a tape recording of two male speakers simultaneously reading unrelated passages, and was dubbed onto the sentence set W and X master tapes at a 0 dB signal-to-noise ratio.

The 0 dB signal-to-noise ratio was judged by the experimental subjects to produce a degree of listening difficulty comparable to that experienced in group conversations. Sentence sets Y and Z were always presented in quiet. When presented to a group of five persons with hearing sensitivity within normal limits, sentence sets W and X were found to be 93% intelligible, while sets Y and Z were 100% intelligible.

Filter Conditions and Procedures

Prior to the pre-test evaluation and test sessions, the PAL-8 and masking stimulus master tapes were subjected to high pass filtering in order to conform to the suggested "ideal electro-acoustic specifications for hearing aids" of Davis (1947), i.e., rising 4 to 6 dB per octave high frequency emphasis from 300 to 4000 Hz, with sharp cutoffs above and below. This was accomplished by feeding the output of one Ampex 602-2 Tape Recorder into the Bruel and Kjaer Model 124 Spectrum Shaper, with appropriate filter settings, and recording the output of the spectrum shaper on a second Ampex 602-2 Tape Recorder. The masking stimulus was then dubbed onto the PAL-8 Sentence Set W and X tapes with a 0 dB signal-to-noise ratio. These high frequency emphasis tapes were then used as test tapes for presentation of the four experimental filtering conditions. The high frequency emphasis frequency response used for shaping the test tapes is shown in Figure 1, Appendix B.

The four experimental filtering conditions presented to each subject were:

> Condition HF (High Frequency Emphasis) -- Test tapes presented with high frequency emphasis of 4 to 6 dB per octave between 300 and 4000 Hz.
>
> Condition BR (Band Rejection) -- Test tapes subjected to band rejection filtering at selected center frequencies from 1600 to 4000 Hz.
>
> Condition LP (Low Pass) -- Test tapes subjected to low pass filtering below 1600 Hz with an upper cutoff slope of 50 dB per octave.
>
> Condition SA (Subject Adjusted) -- Test tape filtering determined by direct manipulation of the spectrum shaper attenuators by the subject.

Presentation of the four filtering conditions was accomplished by feeding the high frequency emphasis test tape output from an Ampex 602-2 Tape Recorder into the Bruel and Kjaer Spectrum Shaper, set to the appropriate attenuator settings, and channeling the filtered output through a Grason-Stadler Speech Audiometer into a single TDH-49 earphone.

Attenuator settings for Condition HF were at the 0 dB position, as the test tapes had previously received the required high frequency shaping. Attenuator settings for Condition LP were at 0 dB from 400 to 1600 Hz and at total attenuation above 1600 Hz. Attenuator settings for Conditions HF and LP were the same for all subjects.

Attenuator settings for Conditions BR and SA were determined individually for each subject during the pre-test evaluation. Settings for Condition BR were determined by having the subject listen to a tape recorded passage of continuous discourse, previously subjected to high frequency emphasis filtering, as the experimenter selectively rejected 1/3 octave frequency bands with center frequencies from 1600 to 4000 Hz. As each band rejection was made, the subject indicated whether the speech became more or less intelligible. Center frequencies of band rejections leading to increased judged intelligibility were noted for each subject and used for that subject in the Filter Condition BR test presentation.

Condition SA settings were obtained for each subject by having him listen to the passage of continuous discourse while he manipulated the spectrum shaper attenuators within the frequency range of 400 to 4000 Hz until he judged the speech to be most intelligible. The filter attenuator settings at maximum judged intelligibility were noted for each subject and used for Condition SA presentations.

Practice responding to PAL-8 type sentence material under each of the four experimental filtering conditions was provided during the pre-test evaluation. Speech reception thresholds were established for each of the experimental filtering conditions using a tape recorded list of Auditory Test W-1 spondee words, and most comfortable loudness levels were established for the passage of continuous discourse. Both the spondee words and passage of continuous discourse were recorded by the same speaker used to record the PAL-8 test tapes. During all speech presentations calibration adjustments of the speech audiometer output were made to maintain an approximate 0 dB VU meter indication.

Test Presentation

Subjects were seated in a double-walled IAC Test Suite during the testing procedure. The PAL-8 test tapes were presented with appropriate filtering to comply with the four experimental conditions established for each subject. Each sentence set was presented once under each of the four filtering conditions. Order of presentation of quiet vs. masked sentence sets was random within experimental filtering conditions, and order of presentation of filtering conditions to subjects was random with the restriction that no experimental filtering condition or sentence set be presented in succession. Test tapes for each experimental filtering condition were presented at MCL +6 dB.

Subjects responded to the sentence set questions by underlining their choice of answers on an answer sheet. A silent interval of seven seconds was provided for making a choice. Subjects were instructed to answer each question, guessing if necessary.

CHAPTER III

Results and Discussion

Results

Speech intelligibility scores were obtained for the PAL-8 Sentence Sets from ten subjects representing two sensori-neural hearing loss contour types. Each subject responded to each of the four PAL-8 Sentence Sets under each of the four filter conditions. The speech intelligibility score obtained for each sentence set presentation represents the number of correct responses to that 25-sentence set. Speech intelligibility scores obtained from individual subjects are presented in Table II.

Combined intelligibility scores for subjects within hearing loss contour types, under filter and presentation conditions, are presented in Table III along with total filter and presentation scores for all ten subjects. The intelligibility score totals are expressed in terms of the percentage of responses correct.

Speech intelligibility scores were subjected to a nested factorial analysis of variance in order to evaluate the proposed null hypotheses. Results of the analysis of variance treatment are found in Table IV.

TABLE II

Speech Intelligibility Scores Obtained under the Experimental Filter Conditions*

Filter Cond.	HF				BR				LP				SA			
Sent. Set	W	X	Y	Z	W	X	Y	Z	W	X	Y	Z	W	X	Y	Z
Hearing Loss Type 1																
Subject 1	7	6	18	15	10	11	17	16	9	9	14	15	6	8	16	16
Subject 2	14	18	21	18	11	16	21	22	14	17	20	22	16	14	24	20
Subject 3	8	6	13	10	7	4	9	8	8	5	8	8	7	4	12	7
Subject 4	8	7	15	15	7	10	19	9	8	7	10	10	8	8	16	11
Subject 5	12	14	20	20	11	13	20	18	9	9	14	11	9	13	21	17
Hearing Loss Type 2																
Subject 6	13	11	20	19	14	15	20	22	10	9	22	16	14	14	18	21
Subject 7	12	12	15	19	10	14	16	14	10	10	18	16	14	13	19	13
Subject 8	12	15	21	19	10	14	20	21	12	15	21	12	10	13	19	20
Subject 9	17	16	22	25	15	21	23	21	18	9	23	25	19	19	24	25
Subject 10	12	17	23	24	9	15	22	24	9	11	22	25	15	19	23	21

*Number of correct responses per 25-sentence set

TABLE III

Intelligibility Score Totals for Hearing Loss Types, Presentation Conditions and Filter Conditions Expressed as Percentages of Correct Responses

Filter Condition	HF	BR	LP	SA
Hearing Loss Type 1: Noise Presentation	40%	40%	38%	37%
Hearing Loss Type 1: Quiet Presentation	66%	64%	53%	64%
Hearing Loss Type 1: Combined Quiet and Noise Presentations	53%	52%	45%	51%
Hearing Loss Type 2: Noise Presentation	55%	55%	45%	60%
Hearing Loss Type 2: Quiet Presentation	83%	81%	80%	81%
Hearing Loss Type 2: Combined Quiet and Noise Presentations	69%	68%	63%	71%
Noise Presentation Total	47%	47%	42%	49%
Quiet Presentation Total	74%	72%	66%	73%
Filter Condition Total	61%	60%	54%	61%

TABLE IV

Analysis of Variance Results

Source	df	Sum of Squares	Mean Square	F	F(.05)
Contour types	1	748.22	748.22	4.53	5.32
Subjects within types	8	1320.05	165.01	30.91**	2.05
Filter conditions	3	79.72	26.58	5.74**	3.01
Presentation conditions	1	1587.60	1587.60	129.27**	5.32
Filter x presentation interaction	3	3.05	1.02	0.24	3.01
Filter x type interaction	3	6.72	2.24	0.48	3.01
Presentation x type interaction	1	14.40	14.40	1.17	5.32
Filter x presentation x type interaction	3	54.85	18.28	4.39*	3.01
Filter x subject interaction	24	111.05	4.63	0.87***	1.65
Presentation x subject interaction	8	98.25	12.28	2.30*	2.05
Filter x presentation x subject interaction	24	99.85	4.16	0.78	1.65
Error	80	427.00	5.34		
Total	159	4550.78			

*Significant at the .05 level

**Significant at the .01 level

***Analysis of the filter x subject interaction, with hearing loss types treated independently, revealed no significant interaction effect.

TABLE V

SRT's and MCL's Obtained under the Four Filter Conditions and a Flat Frequency Response

Filter Cond.	Flat Freq. Resp.		HF		BR		LP		SA	
HL Type 1	SRT	MCL	SRT	MCL	SRT	MCL	SRT	MCL	SRT	MCL
Subj. 1	74	78	72	80	72	80	74	80	74	78
Subj. 2	70	84	76	84	70	84	70	84	82	86
Subj. 3	64	94	64	92	60	92	62	88	62	90
Subj. 4	70	92	76	94	74	94	78	92	76	92
Subj. 5	56	76	62	76	58	74	56	74	62	74
HL Type 2										
Subj. 6	26	66	34	66	36	64	34	64	34	64
Subj. 7	10	56	20	66	20	58	28	64	34	70
Subj. 8	26	74	52	74	58	72	54	74	56	74
Subj. 9	22	68	34	66	28	64	30	64	34	64
Subj. 10	34	60	46	64	40	62	40	64	38	60

Speech reception thresholds and most comfortable loudness levels obtained under the four filter conditions for each subject are presented in Table V along with measures obtained using a flat frequency response.

TABLE VI

Band Rejection Center Frequencies for Filter Condition BR

	Band Rejection Center Frequency (Hz)				
HL Type 1					
Subject 1				3150	4000
Subject 2	1600	2000			
Subject 3	1600		2500	3150	
Subject 4		2000		3150	4000
Subject 5			2500	3150	4000
HL Type 2					
Subject 6		2000	2500		
Subject 7	1600	2000			
Subject 8	1600	2000			
Subject 9			2500	3150	
Subject 10	1600	2000			

Band rejection center frequencies chosen by each subject for Condition BR are presented in Table VI. Filter Condition SA frequency response curves for each subject are presented in Appendix D.

Curve A in Appendix D represents the frequency response characteristic for a constant level pure tone input. Curve B input was speech noise obtained from the Grason-Stadler Speech Audiometer and subjected to 4 to 6 dB per octave high frequency emphasis filtering. The speech noise spectrum approximates the long-time average spectrum of speech and illustrates the spectrum shaper output for a speech signal input.

Discussion

Analysis of variance

Based on statistical analysis of the obtained speech intelligibility scores, the following decisions can be made concerning the proposed null hypotheses. Table IV indicates insufficient experimental evidence for rejection of the null hypothesis of no difference in speech intelligibility of the two hearing loss contour types. Although mean intelligibility scores for the two types do differ, Type 1 being 12.6 and Type 2 16.9, the difference was not large enough to reach significance at the .05 level with only five subjects per type. Had a larger number of subjects been included in each type, a significant difference between types might have been found. The lack of significance may also be partially explained by the large subject-within-type variation which was significant at beyond the .01 level; and is reflected by an intelligibility score standard deviation of 3.16 for subjects within types.

Differences in threshold contours of subjects within hearing loss contour types may be responsible for the large subject-within-type variation observed. Had subjects within types been more homogeneous, the subject-within-type variation might have been reduced. It should be noted, however, that persons having similar pure tone threshold contours frequently evidence substantial differences in speech intelligibility.

The observed overall difference in the effect of filter conditions on speech intelligibility enables rejection of the null hypothesis at the .01 level. Table III shows Filter Condition HF to yield the largest percentage of correct responses, followed in order by Filter Conditions SA, BR and LP. Filter Conditions HF and SA provided the same percentage of correct responses, 61%, while Condition BR reached 60%. Filter Condition LP was found to provide the least percentage of correct responses, 54%.

Application of Duncan's New Multiple-range Test (Steel and Torrie, 1960) revealed no significant differences in the effects of Filter Conditions HF, BR and SA. However significant differences, .05 level, were found to exist between Condition LP and each of the other filter conditions, i.e., Filter Condition LP speech intelligibility significantly poorer than found for Filter Conditions HF, BR or SA.

The above finding does not lend support to the experimental hypothesis of improved speech intelligibility for persons with sensorineural hearing losses through selective band rejection filtering. When compared to Filter Conditions HF and SA, no improvement in speech intelligibility is found for Filter Condition BR. It appears that the specific band rejection filtering procedure employed did not reduce cochlear distortion of the speech signal sufficiently to improve speech intelligibility.

The finding that Filter Condition LP intelligibility was significantly poorer than for Conditions HF, BR or SA points out the importance of preserving frequency components above 1600 Hz in auditory amplification systems designed for use by sensori-neural hearing-impaired individuals. Harris (1965) and Kryter, William and Green (1962) demonstrated the increased importance of frequencies above 1500 Hz for speech intelligibility by hearing-impaired individuals, particularly under the presence of masking or distortion. It appears that although the higher frequency speech components may be subjected to some cochlear distortion, they nevertheless contribute significantly to speech intelligibility.

The filter condition results are compatible with the finding of Davis (1947) that most patients, regardless of the nature of their hearing loss, hear best with moderate high frequency emphasis amplification; although the total intelligibility score for Filter Condition HF was not found to be significantly larger than for Filter Conditions BR or SA. It should be noted however, that the total intelligibility score for Filter Condition SA, which the subjects subjectively judged most intelligible, was slightly poorer than that found for Filter Condition HF. This finding illustrates the difficulty experienced by hearing-impaired individuals in making subjective evaluations of amplification systems.

It also indicates the possible inadequacy of amplification selection procedures based solely on subjective judgements of improved speech intelligibility.

Reference to Table IV reveals no significant filter-by-type interaction, nor was there a significant filter-by-subject-within-types interaction. It appears that both hearing loss types were affected by the filter conditions in the same manner, and that subjects, within the two hearing loss types, tended to achieve best intelligibility with Filter Condition HF followed by Conditions SA, BR and LP.

A significant difference in speech intelligibility measured under the noise and quiet presentation conditions was found. The noise presentation yielded an overall mean intelligibility score of 11.5, or 46% correct responses; while the quiet presentation yielded a mean score of 17.8, or 71% correct responses. The above finding substantiates for sensori-neural hearing-impaired individuals the deleterious effect of speech or noise maskers on speech intelligibility previously found for normal-hearing individuals (Miller, 1947; Miller and Nicely, 1955).

No significant filter-by-presentation interaction was observed, indicating that the quiet presentation was consistently more intelligible than the noise presentation for all filter conditions. Presentation-by-type interaction was also found to be non-significant; indicating increased intelligibility under the quiet presentation for both hearing loss types. However, a significant filter-by-presentation-by-type interaction was evidenced. It appears that hearing loss contour Type 1 subjects scored relatively poorer for Filter Condition LP under the quiet presentation, while the Type 2 subjects scored relatively poorer for Filter Condition LP under the noise presentation.

A significant presentation-by-subject interaction was also found. This interaction reveals that although all subjects obtained higher speech intelligibility for the quiet presentation, not all subjects showed equal gains in intelligibility from the noise-to-quiet presentation. The filter-by-presentation-by-subject interaction was not found to be significant, indicating that most subjects show a consistent trend of improved speech intelligibility under the quiet presentation for all filter conditions.

In review, the following null hypotheses were rejected at or beyond the .05 level of significance:

1. There are no significant differences in speech intelligibility of subjects within hearing loss type groups.
2. There are no significant differences in the effects of the four filter conditions on speech intelligibility.
3. There are no significant differences in speech intelligibility due to the two presentation conditions.
4. There are no significant interaction effects among filter conditions, presentation conditions and hearing loss types affecting speech intelligibility.
5. There are no significant interaction effects among presentation conditions and subjects affecting speech intelligibility.

Experimental evidence did not warrant rejection of the remaining null hypotheses at the .05 level of significance.

Speech reception thresholds

As can be seen in Table V, most subjects obtained quite similar SRT's under the four filter conditions. SRT's for Hearing Loss Contour Type 1 subjects obtained for the flat frequency response also show close agreement to the filtered speech SRT's. Type 2 subjects, however, consistently obtained lower SRT's under the flat frequency response. It appears that because of their normal low frequency thresholds, these subjects experience larger loss of low frequency information under the high frequency emphasis filtering than do the Type 1 subjects. As a larger proportion of the speech signal sound pressure level was shifted to higher frequencies by the high frequency emphasis filtering these subjects required increased overall sound pressure levels to raise the low frequency speech components to threshold levels.

Most comfortable loudness levels

MCL's established under the four filter conditions are in close agreement. Contrary to the finding for SRT's, subjects in both hearing loss types show essentially no change in MCL from the flat to filtered speech conditions. It can be noted, however, that most Type 1 subjects evidence a greatly reduced dynamic range from SRT to MCL when compared to the Type 2 subjects. The recruitment phenomena may be responsible for the reduced dynamic ranges found for the Type 1 subjects. The larger dynamic ranges found for the Type 2 subjects may be accounted for by the substantially lower SRT's obtained by the Type 2 subjects through the use of their relatively normal low frequency hearing. Hirsh, Reynolds and Joseph (1954) established the major contribution of frequencies below 1500 Hz to the intelligibility of spondee words.

Attenuator settings for conditions BR and SA

Table VI reveals that seven of the ten subjects indicated maximum speech intelligibility for Filter Condition BR with two 1/3 octave rejections, while three subjects requested three 1/3 octave rejections. No subject limited the Condition BR filtering to rejection of a single 1/3 octave band. It is of interest to note that nine of the thirteen band rejections requested by Type 1 subjects were at or above 2500 Hz; while eight of the nine rejections requested by Type 2 subjects were at or below 2500 Hz. It appears that Type 1 subjects preferred rejections within the frequency range most severely impaired while Type 2 subjects preferred rejections within the frequency range experiencing the maximum rate of decrease in threshold sensitivity. These two frequency regions may represent, for the two respective hearing loss contour types, the speech signal frequencies contributing maximally to cochlear distortion.

Examination of Appendix D frequency response curves reveals that most subjects adjusted the spectrum shaper attenuators under

Filter Condition SA to produce some high frequency emphasis amplification. However, considerable variation is found among subjects in the amount and slope of high frequency emphasis provided. Most subjects commented on the difficulty experienced in adjusting the filter attenuators to provide noticeable improvements in speech intelligibility. Considerable changes in filter attenuator settings were often made by a subject with no effect on his subjective evaluation of the speech intelligibility provided.

Comparison of Condition BR rejection frequencies and Condition SA frequency response curves evidences no clear-cut relationship. Subjects 2, 5 and 7 provided a minimum of attenuation for Condition SA at center frequencies rejected in Condition BR. Most subjects, however, tended to provide substantial attenuation for Condition SA within the same frequency range subjected to rejection in Condition BR. The failure to obtain a more precise relationship between the Filter Condition BR and SA frequency attenuations may reflect the difficulty experienced by hearing-impaired individuals in making subjective evaluations of improved speech intelligibility.

CHAPTER IV

Summary and Conclusions

Summary

Purpose

The purpose of this investigation was to determine whether or not individuals with high frequency sensori-neural hearing losses could achieve improved speech intelligibility through selective band rejection filtering of frequency regions of the speech signal which possibly contribute more to cochlear distortion than to intelligibility.

Procedure

Monaural speech intelligibility scores for PAL-8 Sentence Sets were obtained from ten subjects representing two sensori-neural hearing loss contour types: Type 1 -- relatively flat losses, and Type 2 -- ski slope losses. Intelligibility scores were obtained from the five subjects within each hearing loss contour type under four filtering conditions:

Condition HF -- High frequency emphasis
Condition BR -- Band rejection
Condition LP -- Low pass
Condition SA -- Subject adjusted

Filter Condition HF provided 4 to 6 dB per octave high frequency emphasis from 300 to 4000 Hz with sharp cutoffs above and below. Filter Conditions BR, LP and SA were obtained by re-filtering the Condition HF high frequency emphasis response. Filter Condition LP provided low pass filtering with an upper cutoff frequency of 1600 Hz. Filter settings for Conditions HF and LP were the same for all subjects.

Filter settings for Conditions BR and SA were determined individually for each subject. Settings for Condition BR were determined by having the subject listen to a passage of continuous discourse, previously subjected to high frequency emphasis filtering, as the experimenter rejected 1/3 octave bands at center frequencies from 1600 to 4000 Hz. Center frequencies of band rejections leading to increased judged intelligibility by the subject were noted and used for that subject in the Filter Condition BR test presentation.

Condition SA settings were obtained for each subject by having him listen to the passage of continuous discourse while he manipulated the filters, within the frequency range of 400 to 4000 Hz, until he judged the speech most intelligible. Filter settings at maximum judged intelligibility were noted for each subject and used for his Filter Condition SA presentations.

The effect of each filter condition on speech intelligibility was determined under two presentation conditions: in quiet and in the presence of a competing speech masking stimulus at 0 dB signal/noise ratio. Filtered speech test materials were presented to each subject at 6 dB above the most comfortable loudness level established for that filter condition.

Results

The obtained speech intelligibility scores were subjected to a nested factorial analysis of variance which indicated a significant difference (.01 level) in the effects of filter conditions on speech intelligibility. Application of Duncan's New Multiple Range Test revealed Filter Condition LP speech intelligibility to be significantly poorer than for Conditions HF, BR or SA; while no significant differences were found to exist among Filter Conditions HF, BR and SA. A significant difference (.01 level) in speech intelligibility measured under the two presentation conditions was also noted, with the masking stimulus causing a substantial reduction of speech intelligibility. In addition, significant individual differences (.01 level) in speech intelligibility were found to exist among subjects within the two hearing loss contour types. However, the difference in average speech intelligibility of the two hearing loss contour type groups did not reach significance at the .05 level.

Two interaction effects were found to be significant at the .05 level: the presentation-by-subject interaction and the filter-by-presentation-by-subject interaction. The remaining filter-by-presentation, filter-by-hearing loss type, presentation-by-hearing loss type, filter-by-subject, and filter-by-presentation-by-subject interactions were not significant at the .05 level.

Conclusions

The experimental results do not support the experimental hypothesis of improved speech intelligibility for persons with sensori-neural hearing losses through selective band rejection filtering. The specific band rejection filtering procedure employed apparently did not reduce cochlear distortion of the speech signal sufficiently to improve intelligibility. The findings do demonstrate the important contribution of frequencies above 1600 Hz to speech intelligibility by individuals with sensori-neural hearing losses. It appears that although the higher frequency speech components may be subjected to some cochlear distortion, they nevertheless contribute significantly to intelligibility. The results also illustrate the difficulty experienced by hearing-impaired individuals in making subjective evaluations of speech amplification systems, and the detrimental effect of competing speech masking on speech intelligibility.

Implications for Further Study

Although the present investigation failed to demonstrate gains in speech intelligibility through the specific band rejection filtering approach examined, the findings do give impetus to the search for better ways of utilizing higher frequencies in amplification systems designed for use by hearing-impaired individuals. A re-examination of band rejection filtering with different filter bandwidths, attenuation slopes and center frequencies might lead to the desired improvement in intelligibility. Perhaps in a longitudinal study subjects provided auditory training and listening experiences with this type of amplification could achieve improved speech intelligibility. Even though no objective gains in intelligibility are found, selective band rejection filtering might provide an amplification response producing decreased cochlear distortion and tolerance problems and result in a more willing acceptance of amplification by hearing-impaired individuals.

It is hoped that the present investigation has provided some insight into the need for and problems of "selective amplification" based not solely on pure tone sensitivity but rather on the capacity of the impaired auditory system to process the speech signal.

APPENDIX A

Pre-test Evaluation Pure Tone Results
(Threshold levels in dB HL re 1964 ISO standards)

Subject 1

Hearing Loss Type 1

Age: 48

Test Ear: Left

Bekesy: Type 2

Frequency	250	500	1000	1500	2000	3000	4000
AC Threshold	50	55	75	80	75	80	90
BC Threshold	35	55	NR	NR	NR	NR	NR
SISI Score			45%	75%	50%	20%	50%

Subject 2

Hearing Loss Type 1

Age: 53

Test Ear: Right

Bekesy: Type 2

Frequency	250	500	1000	1500	2000	3000	4000
AC Threshold	50	60	85	NR	110	110	NR
BC Threshold	NR	NR	NR	NR	NR	NR	NR
SISI Score			100%	CNT	CNT	CNT	CNT

Subject 3

Hearing Loss Type 1 Age: 50

Test Ear: Right Bekesy: Type 2

Frequency	250	500	1000	1500	2000	3000	4000
AC Threshold	60	60	65	65	65	60	60
BC Threshold	NR	NR	NR	NR	NR	55	50
SISI Score			100%	100%	100%	100%	100%

Subject 4

Hearing Loss Type 1 Age: 51

Test Ear: Left Bekesy: Type 2

Frequency	250	500	1000	1500	2000	3000	4000
AC Threshold	70	80	75	75	60	70	70
BC Threshold	NR	NR	NR	NR	NR	NR	NR
SISI Score			100%	100%	100%	100%	100%

Subject 5

Hearing Loss Type 1 Age: 64

Test Ear: Left Bekesy: Type 2

Frequency	250	500	1000	1500	2000	3000	4000
AC Threshold	45	50	60	70	75	80	80
BC Threshold	NR	45	55	NR	60	NR	NR
SISI Score			0%	100%	100%	100%	40%

Subject 6

Hearing Loss Type 2 Age: 48

Test Ear: Right Bekesy: Type 2

Frequency	250	500	1000	1500	2000	3000	4000
AC Threshold	5	5	5	50	65	85	80
BC Threshold	10	15	5	55	NR	NR	NR
SISI Score			0%	50%	90%	85%	75%

Subject 7

Hearing Loss Type 2 Age: 39

Test Ear: Left Bekesy: Type 2

Frequency	250	500	1000	1500	2000	3000	4000
AC Threshold	10	5	25	85	75	80	85
BC Threshold	5	15	15	NR	NR	NR	NR
SISI Score			0%	40%	45%	65%	50%

Subject 8

Hearing Loss Type 2 Age: 50

Test Ear: Right Bekesy: Type 2

Frequency	250	500	1000	1500	2000	3000	4000
AC Threshold	10	10	40	60	75	85	80
BC Threshold	10	10	45	NR	NR	NR	NR
SISI Score			30%	75%	90%	100%	100%

Subject 9

Hearing Loss Type 2 Age: 67

Test Ear: Right Bekesy: Type 2

Frequency	250	500	1000	1500	2000	3000	4000
AC Threshold	10	20	30	85	90	90	85
BC Threshold	10	25	30	NR	NR	NR	NR
SISI Score			0%	90%	100%	100%	100%

Subject 10

Hearing Loss Type 2 Age: 82

Test Ear: Right Bekesy: Type 2

Frequency	250	500	1000	1500	2000	3000	4000
AC Threshold	20	20	35	50	60	80	80
BC Threshold	20	20	35	50	55	NR	NR
SISI Score			60%	100%	100%	95%	100%

APPENDIX B

Spectrum Shaper Frequency Response Characteristics

Figure 1: Curve A -- Spectrum Shaper Flat Frequency Response

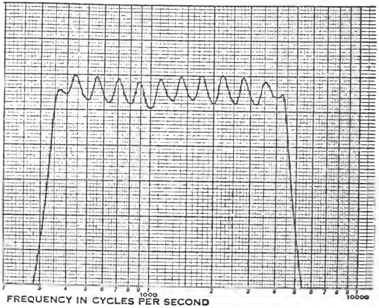
Curve B -- Spectrum Shaper High Frequency Emphasis Response

(Major ordinate divisions of Curves A and B in relative 5 dB steps)

TABLE I: Filter Condition BR Band Rejection Characteristics

Figure 1

Curve A - Spectrum Shaper Flat Frequency Response



Curve B

Spectrum Shaper High Frequency Emphasis Response

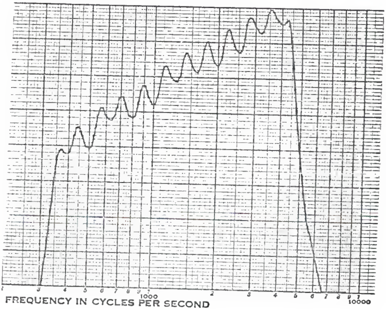


TABLE B-1

Filter Condition BR - Band Rejection Filter Characteristics

Center Frequencies	Rejection Attenuation	Rejection Bandwidth(Hz)	Rejection Band Limits(Hz)
1600 Hz	3dB	400	1400-1800
	10dB	240	1460-1700
	20dB	100	1520-1620
	30dB	20	1580-1600
2000 Hz	3dB	450	1750-2200
	10dB	260	1850-2110
	20dB	100	1910-2010
	30dB	50	1950-2000
2500 Hz	3dB	600	2200-2800
	10dB	400	2300-2700
	20dB	200	2400-2600
	30dB	100	2450-2550
3150 Hz	3dB	700	2800-3500
	10dB	500	2900-3400
	20dB	150	3050-3200
	30dB	100	3100-3200
4000 Hz	3dB	900	3500-4400
	10dB	550	3700-4250
	20dB	250	3850-4100
	30dB	100	3900-4000
(1600, 2000)	3dB	900	1400-2200
	10dB	700	1450-2150
	20dB	450	1550-2000
	30dB	170	1680-1850

Center Frequencies	Rejection Attenuation	Rejection Bandwidth(Hz)	Rejection Band Limits(Hz)
(2000, 2500)	3dB	1050	1750-2800
	10dB	900	1800-2700
	20dB	550	1950-2500
	30dB	200	2100-2300
(2500, 3150)	3dB	1400	2200-3600
	10dB	1100	2300-3400
	20dB	700	2450-3150
	30dB	250	2650-2900
(3150, 4000)	3dB	1600	2800-4400
	10dB	1300	2900-4200
	20dB	900	3100-4000
	30dB	300	3300-3600

APPENDIX C

PAL-8 Sentence Sets and Answers

PAL-8 SENTENCE SET W

1. In what month do we celebrate Christmas?
25th Gifts January December

2. Butter is made from:
Cheese Churns Dairies Milk

3. The number of fingers on an average hand is:
10 2 5 Nails

4. The cold weather ends in:
Furnaces Winter Tickling Spring

5. How many "L's" are there in the alphabet?
Twenty-six One L M

6. Bows are used to shoot:
Indians Arrows Rapids Guns

7. Underline the word that contains the letter "T."
Tear Cigar Vamp Do

8. What is the sum of two plus five?
11 10 9 7

9. Underline the word "chunk."
Junk Chump Shrunk Chunk

10. Which is smaller, six or two?
4 2 8 1

11. Underline "ladder."
Litter Ladder Letter Latter

12. What is six times two?
12 4 8 3

13. The coldest land is:
Alaska Ice Eskimo Mines

14. Something that weighs a great deal is:
Heavy Dog Expensive Card-player

15. What is seven and five?
2 35 7 12

16. The thing which is salty is:
Ocean Rotten Food Broken-down

17. What is the number before sixty-nine?
69 58 70 68

18. Between the head and leg is the:
Leg Body Head Foot

19. Underline the lowest of these numbers.
8 4 6 3

20. Which meal is nearer midnight?
10 A.M. Lunch Supper 11 P.M.

21. The longest word of these four is:
7 4 Car Umbrella

22. We measure heat with a:
Hot Summer Thermometer Stove

23. The man who fights with gloves is a:
Soldier Bully Cold Boxer

24. Is eight more than three plus three?
6 Yes No 11

25. A mile race has:
Kindness Slow Runners Food

PAL-8 SENTENCE SET X

1. What month comes after September?
August October November Autumn

2. London is the name of a city in:
Sunday England Washington Rome

3. Name the cloth made by a worm.
Silk Fish Caterpillar Worm-hole

4. What is the number to the right of thirty-eight?
30 38 25 72

5. When it gets very cold, water becomes:
North-pole Winter Ice Mines

6. Half of ten is:
10 1/2 5 20 10

7. Tobacco is smoked in:
Pipes Fire Windows Leaves

8. You can get drunk from:
Donuts Soup Alcohol Wasp

9. A wolf is like a wild:
Den Sheep Dog Bark

10. A train is used for:
Lifting Burning Traveling Flying

11. Is milk the color of snow?
No White Yes Winter

12. A racket is used for playing:
Music Tennis Shooting Loud noise

13. What makes your feet slip?
Keyhole Mattress Mat Floorwax

14. What insect does honey come from?
Hive Bee Cricket Treasury

15. A man who cannot see is:
Blind Glasses Dark Invisible

16. The taste of a ripe apple is:
Round Red Sweet Cider

17. The tires on a car are made of:
Round Steel Rubber Glass

18. You catch fish with:
Forks Lassoes Hooks Food

19. Rubies are the same color as:
Diamonds Blood Green Sky

20. Coal is burned in:
Ground Stoves Cellars North-pole

21. On a clear day the weather is:
Gray Sunny Blue Picnic

22. Which of these numbers is nearest fourteen?
13 17 Baby 2 Weeks

23. Underline the smallest sum of money.
Dwarf Flower 5 Cents Mouse

24. The winner of a race is:
Referee First Hurdler Last

25. On what material is a newspaper printed?
News Press Paper Reporter

PAL-8 SENTENCE SET Y

1. How much is seven plus four?
   11 28 3 4

2. What language is spoken in the country of France?
   French Spanish Germany Dialect

3. White is the color of:
   Color Black Dark Snow

4. Which is the middle of the week?
   15th Strong Wednesday Sunday

5. Underline the word next to four.
   Quarter Dime Half Four

6. What number comes after eighty?
   40 81 1/2 80

7. Flour is used to make:
   Bread Wheat Garden Vase

8. What letter comes after "B"?
   E H W C

9. What is the number to the left of five?
   11 9 5 Hive

10. When does the moon shine?
    Day Night Sun Sky

11. How many legs does a duck have?
    2 4 1 Webs

12. Which goes with the greatest speed?
    Horse Airplane Boat Locomotive

13. Where is Paris located?
    New York Compass France England

14. Which of the following has no shell?
    Tortoise Oyster Turtle Shark

15. The thing without any legs is:
    Centipede Fish Man Dog

16. How many minutes are there in half an hour?
45 30 15 4

17. Underline the last one of these words.
Ten Judgement One Old

18. How much is nine minus three?
6 27 15 12

19. The thing which cannot fly is:
Eagle Airplane Skyscraper Sparrow

20. The figure with more than three sides is:
Flag Square Triangle Over-weight

21. A girl with light colored hair is:
Brown Brunette Blonde Redhead

22. A good fight needs good:
Boxers Lantern Eyes Pilot

23. The one which eats grain is:
Tiger Horse Barn Cancer

24. A person with much money is:
Rich Fat Bank Bee

25. The color of cherries on trees is:
Trees Sweet Brown Red

PAL-8 SENTENCE SET Z

1. A wheel is found on a:
   [✓ Wagon] Circle Fishing-rod Shoe

2. Pearls are found in:
   [✓ Oysters] Dormitories Hair Books

3. When we add five to twelve, we get:
   Lunch [✓ 17] 21 7

4. Which of these is the least loud?
   Crime Short Hoarse [✓ Whisper]

5. Name the sound made by a cat.
   Squeak Roar Bark [✓ Purr]

6. Before it becomes a frog, it is called a:
   Swindle Mist [✓ Tadpole] Puppy

7. Is a hill larger than a mountain?
   Yes Mt. Everest Drinking-water [✓ No]

8. Books are printed on a:
   Compass [✓ Printing-press] Author Feet

9. Underline the word "bun".
   Gum Gun [✓ Bun] Bum

10. A rink is used for:
    [✓ Skating] Keeping Money Fur Coats Getting Married

11. You enclose letters in:
    Meals Fire-engines Mailman [✓ Envelopes]

12. Which meal do you eat at noon ?
    Meals Breakfast Supper [✓ Lunch]

13. What is twice two?
    [✓ 4] 75 2 50

14. Which object sparkles the most?
    [✓ Diamond] Lead Expensive Elephant

15. When does the sun set?
    [✓ Evening] West Red Chair

16. A worm is used for:
Eating Garden Caterpillars [✓ Fishing]

17. A place with books is:
Kitchen Fishing Beautiful [✓ Library]

18. A train is driven by a:
Locomotive [✓ Engineer] Tracks Coach

19. Moving pictures are made by:
Moving Companies [✓ Actors] Film Canvas

20. Which of these is the name of a soldier?
Admiral King Popeye [✓ General MacArthur] Greta Garbo

21. Name the fruit used to make wine.
[✓ Grapes] Fruit Sherry Alcohol

22. When do people sleep?
[✓ Night] Beds Rest Meals

23. What is the name of the smallest human?
Giant Mouse Man [✓ Dwarf]

24. The name of a large state is:
[✓ Texas] Platter Lake Superior Rhode Island

25. Does five plus five make twenty-five?
Yes 5 [✓ No] 10

APPENDIX D

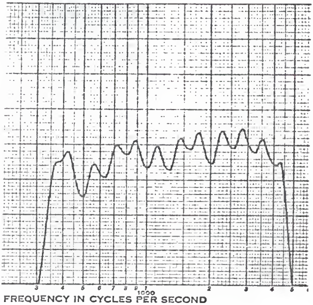
Filter Condition SA Frequency Response Curves for Each Subject

Curve A -- Constant Level Pure Tone Input

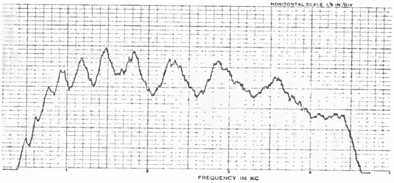
Curve B -- High Frequency Emphasis Speech Noise Input

(Major ordinate divisions of A and B Curves in relative 5dB steps)

Subject 1 - Curve A



Subject 1 - Curve B



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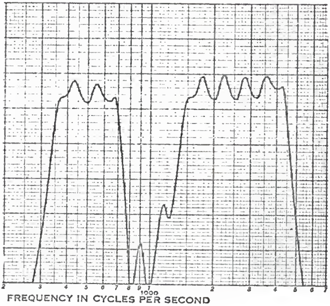

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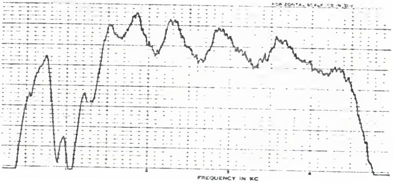

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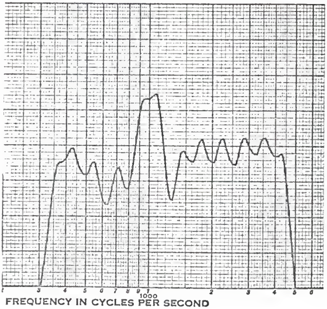

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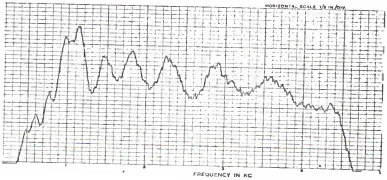

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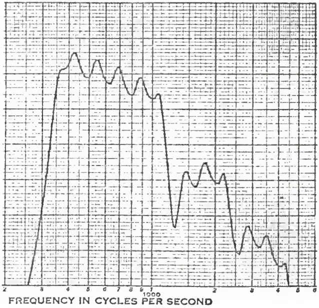
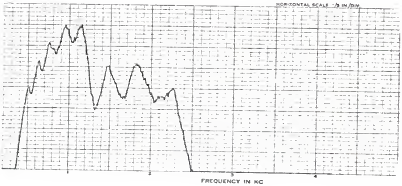


Subject 4 - Curve B



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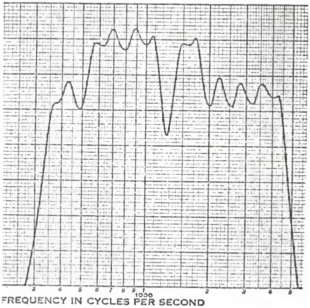
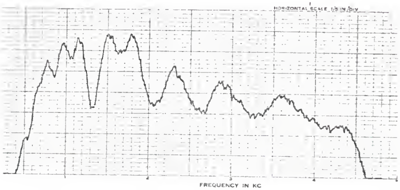


Subject 5 - Curve B



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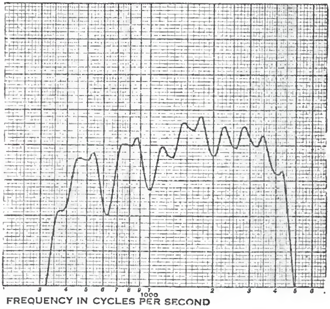

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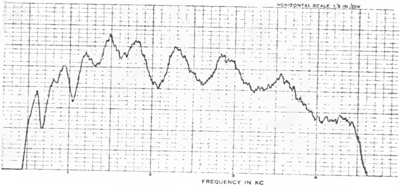

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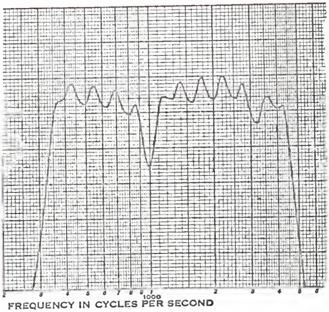

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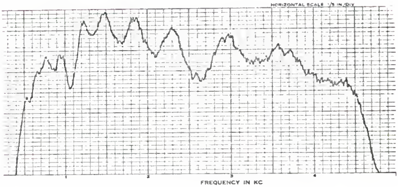
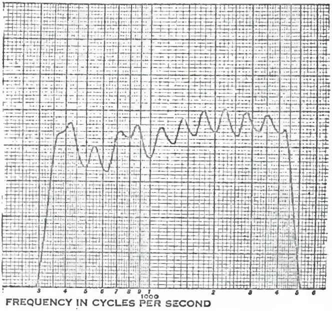


Subject 8 - Curve A



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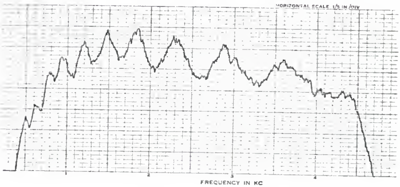
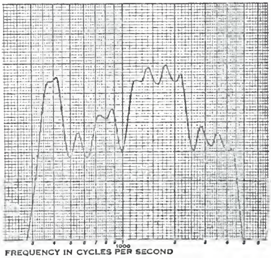


Subject 9 - Curve A



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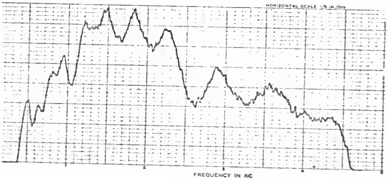
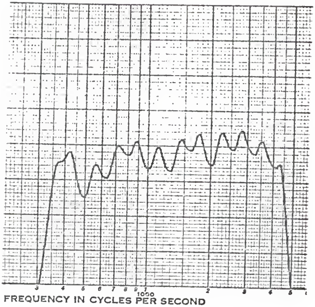
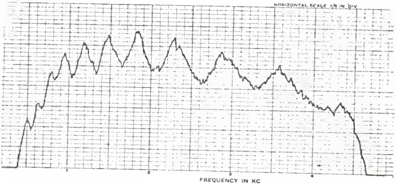


Subject 10 - Curve A



Subject 10 - Curve B



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BIOGRAPHICAL SKETCH

William Darrell Perry was born January 2, 1943, at Ripley, West Virginia. In May, 1961, he was graduated from Catholic High School, Baton Rouge, Louisiana. In May, 1965, he received the degree of Bachelor of Science with a major in Audiology from Louisiana State University. In May, 1967, he received the degree of Master of Arts with a major in Audiology from Louisiana State University. In September, 1967, he enrolled in the Graduate School of the University of Florida. He was appointed to a VA Traineeship at the Veterans Administration Hospital, Gainesville, Florida, in June, 1968, and maintains it until the present time. From 1967 to the present time he has pursued his work toward the degree of Doctor of Philosophy.

William Darrell Perry is married to the former Mary Elizabeth Chase, and is the father of two children. He is a member of the American Speech and Hearing Association.

This dissertation was prepared under the direction of the chairman of the candidate's supervisory committee and has been approved by all members of that committee. It was submitted to the Dean of the College of Arts and Sciences and to the Graduate Council, and was approved as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

August, 1970

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